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Eye-tracking the effect of word order in sentence comprehension in aphasia: evidence from Basque, a free word order ergative language

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ABSTRACT
Agrammatic speakers of languages with overt grammatical case show impaired use of the morphological cues to establish theta-role relations in sentences presented in non-canonical word orders. We analysed the effect of word order on the sentence comprehension of aphasic speakers of Basque, an ergative, free word order and head-final (SOV) language. Ergative languages such as Basque establish a one-to-one mapping of the thematic role and the case marker. We collected behavioural and gaze-fixation data while agrammatic speakers performed a picture-matching task with auditorily presented sentences with different word orders. We found that people with aphasia (PWA) had difficulties in assigning theta-roles in Theme-Agent order. This result is in line with processing accounts. Contrary to previous findings, our data do not suggest a systematic delay in the integration of morphological information in the PWA group, but strong reliance on the ergative case morphology and difficulties assigning thematic roles into the determiner phrases.

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Aphasia; comprehension; Basque; sentence processing; eye-tracking

1. Introduction

Aphasia is a condition present in 21–38% of acute stroke patients, and it frequently persists in chronic stages (Pedersen, Jørgensen, Nakayama, Raaschou, & Olsen, 1995; Pedersen, Vinter, & Olsen, 2003). Although language production impairment is the most noticeable symptom, people with aphasia (PWA) with a variety of different syndromes present persistent sentence comprehension deficits (Caramazza, Basili, Koller, & Berndt, 1981; Vallar, Basso, & Bottini, 1990), independently of production abilities (see Caplan & Waters, 1990; Grodzinsky, 2000 for a review). The deficits that underlie sentence comprehension impairment are still unclear, and the heterogeneity of the clinical profiles increases the research challenges in this area.

In one of the earliest publications on agrammatic sentence comprehension, Caramazza and Zurif (1976) pointed out that PWA make systematic use of heuristic rather than algorithmic strategies to comprehend sentences (e.g. Bayesian computations). That is, PWA infer thematic roles of arguments from semantic and word order information, among other cues. This strategy may be illustrated with reference to the examples (1–2) below:

(1) The boy washes the dish.

(2) The nurse calls the doctor.

For correct interpretation of the sentence in (1) the listener may rely solely on lexical comprehension, rather than on syntactic relations. This is because a semantic restriction of "to wash" only allows the animate "boy" to be the agent of the action and not the inanimate "dish". Therefore, it is expected that PWA with spared lexical comprehension will not have problems understanding such a sentence.

However, a sentence such as (2) shows that lexico-semantic information is not always sufficient to identify who performs the action, since both "nurse" and "doctor" are plausible agents of the action (i.e. "to call"). Sentences such as (2) are hence known as "semantically reversible constructions". In such structures in English, word order information plays an important role. It is widely accepted in linguistics that languages

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have a base word order, which is, generally, the order of declarative active sentences where all information is new (Comrie, 1981; e.g. Subject-Verb-Object in English, and Subject-Object-Verb in Japanese). Sentences with other word orders are assumed to be derived from the base word order. Previous research has shown that PWA retain sensitivity towards the base word order of their language, and that they use this knowledge to infer the thematic roles of sentence constituents (i.e. Agent-Theme (A-T); Bates, Friederici, & Wulfeck, 1987), as healthy speakers do (Ferreira, 2003). Conversely, the comprehension of sentences with derived word order involves higher cognitive demands as suggested by greater error rates and longer reaction times (RTs) in both PWA and healthy speakers, respectively (Bastiaanse & Van Zonneveld, 2006; Bornkessel, Schlesewsky, & Friederici, 2002; Caplan & Waters, 2003; Erdocia, Laka, Mestres-Missé, & Rodriguez-Fornells, 2009; Hanne, Sekerina, Vasishth, Burchert, & De Bleser, 2011).

When correct comprehension of sentences cannot be achieved by means of lexical guesswork, the hierarchical relations between constituents have to be considered. This is the reason why PWA are prone to misinterpreting reversible sentences with non-base word order (Berndt, Mitchum, & Haendiges, 1996; Caplan & Futter, 1986; Caramazza & Zurif, 1976; Saffran, Schwartz, & Marin, 1980). In sentences such as (3–5), where both animate determiner phrases (DPs) are the plausible A/T of the verb and the thematic roles display a non-canonical order (i.e. T-A), neither of the heuristic strategies mentioned above leads to the correct interpretation of the sentence. Thus, the listener must necessarily process syntactic structure to infer A-T roles. In fact, it is precisely disentangling the A-T roles in these types of structures that is at the core of the impairment in PWA with agrammatic comprehension.

(3) The nurse is called by the doctor.

(4) It is the nurse whom the doctor called.

(5) The nurse who the doctor called is tall.

However, it is not only the position of the arguments, which affects sentence comprehension deficits, but also the position of the verb. It is still unclear how PWA process the information contained in the verb, but some studies have pointed out that lexical access to the verb and its argument structure in agrammatic aphasia is unimpaired. Using cross-modal lexical decision tasks, Shapiro and Levine (1990) showed that lexical decision times to visually presented stimuli were higher in the vicinity of the verbs with more argument structure options, in both healthy individuals and individuals with agrammatic aphasia. This indicates that the core impairment of people with agrammatic aphasia eradicates on the post-activation process required for the assignment of thematic roles to the phrasal arguments (Grodzinsky, 1986), as suggested by preserved abilities in grammaticality judgement tasks involving argument structure violations (Kim & Thompson, 2004). However, event related potentials (ERP) studies have suggested that the receptive processing of argument structure is incomplete and temporally delayed in PWA (Kielar, Meltzer-Asscher, & Thompson, 2012).

Although the underlying cause of the inability to correctly interpret semantically reversible sentences is far from understood, several hypotheses have been proposed. Two sets of theories can be identified from representational and processing related accounts; the Trace Deletion Hypothesis (TDH; Drai & Grodzinsky, 2006a, 2006b; Grodzinsky, 1986, 1995, 2000) and the Derived Order Problem-Hypothesis (DOP-H; Bastiaanse & Van Zonneveld, 2006), respectively. The main difference between the two theories is that the TDH, heavily relying on the Government and Binding (GB) model of grammar (Chomsky, 1981), claims that aphasic individuals suffer from a representational deficit, whereas the DOP-H is a processing based account, largely neutral as to a specific model of grammar. We discuss the particulars of each proposal in the next section.

Based on the tenets of the GB (Chomsky, 1981), Grodzinsky proposed the TDH (1986, 1995, 2000; see Drai & Grodzinsky, 2006a, 2006b for a later revision). In the GB model of generative grammar (Chomsky, 1981), upon which Grodzinsky's hypothesis is based, syntactically displaced constituents are assumed to have moved from their based generated position where they leave a trace. Thus, sentence comprehension requires keeping track of both the element in the derived position and the trace left in the base-generated position. The TDH postulates that inability to represent the trace is the underlying cause of the comprehension deficits in PWA when confronted with sentences such as (4–5). According to this hypothesis, since the trace is missing from syntactic representation, individuals with Broca's aphasia cannot assign a thematic role to the moved argument and can only resort to heuristics. They apply a linear-order based assignment of the thematic roles along the sentence and assign the thematic role of Agent to the first DP encountered in the sentence. The thematic role to the non-moved DP (i.e. "the doctor" in 4–5) is correctly assigned, leaving the aphasic individual with a structure with two Agents. When the individuals with Broca's aphasia are forced to select one out of two pictures that only differ in the thematic roles of the persons depicted (e.g. a doctor calling to a nurse and a nurse calling to a doctor), they have to guess (see 4–5). Thus, the TDH predicts that PWAs will perform at ceiling level in their comprehension of semantically reversible sentences with base word order, and at chance-level (between 33.3% and 66.6% correct) in those with derived word orders.

Bastiaanse and Van Zonneveld (2005, 2006) proposed the DOP-H as a processing account. The DOP-H (Bastiaanse & Van Zonneveld, 2005, 2006) states that the production and comprehension of sentences with a derived word order are harder for individuals with agrammatic aphasia than sentences with base word order. For production, the effect is that PWA tend to produce sentences in base word order (Bastiaanse & Edwards, 2004; Bastiaanse & Van Zonneveld, 2005). For comprehension, the disorder is mainly visible in semantically reversible sentences, when the arguments are in derived position (e.g. passives and object relatives in English). These sentences with derived word order are more complex and, therefore, harder to process for PWA (Bastiaanse & Van Zonneveld, 2006). Notice that Bastiaanse and Van Zonneveld (2005, 2006) do not assume that the syntactic representations are affected; rather, they propose a disorder that makes it hard (but not always impossible) to process derived word order structures. Some studies attribute such processing deficits to an overall cognitive slowdown across executive functions, memory and attention (e.g. Burkhardt, Avrutin, Piñango, & Ruigendijk, 2008; Burkhardt, Piñango, & Wong, 2003; Caplan, 2006; Caplan & Waters, 1999; Caplan, Waters, DeDe, Michaud, & Reddy, 2007; Dickey, Choy, & Thompson, 2007; Haarmann & Kolk, 1991). For the sentences under study, the DOP-H claims that sentences are harder to process when there is no linear A-T order, regardless of the position of the verb in the sentence. The DOP-H can fully account for comprehension data from agrammatic speakers of languages with rather rigid word order (e.g. English and Dutch; Bastiaanse & Edwards, 2004; English and Swahili; Abuom, Shah, & Bastiaanse, 2013), and flexible word order (e.g. Spanish and Galician; Juncos-Rabadán, Pereiro, & Souto, 2009). Nevertheless, the characterisation of aphasic speakers of languages with case morphology seems to be slightly different.

Languages with overt case morphology mark the arguments of the verb depending on their grammatical function or thematic role. Correlated with this, sentences in these languages display a greater variety of word orders and, therefore, the word order cue is not as strong as in more rigid word order languages, such as English. Several studies have shown that the processing of case morphology is impaired in PWA (German; Burchert, De Bleser, & Sonntag, 2003; Russian; Friedmann, Reznick, Dolinski-Nuger, & Soboleva, 2010; Hebrew; Friedmann & Shapiro, 2003; Serbo-Croatian; Smith & Mimica, 1984; Turkish: Duman, Altınok, Özgirgin, & Bastiaanse, 2011). However, some cross-linguistic comparisons suggest that aphasic speakers of languages with case marking have certain advantages when it comes to processing derived order sentences. For example, aphasic speakers of German perform better in the comprehension of passive sentences than Dutch speakers (Bastiaanse & Edwards, 2004; Burchert et al., 2003; see also Bates et al., 1987).

In conclusion, individuals with agrammatic aphasia have problems comprehending semantically reversible sentences when the order of the arguments is derived. Nevertheless, one could wonder whether this deficit is language dependent or not. To gain insight into this topic, more studies of PWA speaking free word order languages with rich case morphology are necessary.

One of the differences between the TDH (Drai & Grodzinsky, 2006a, 2006b; Grodzinsky, 1986, 1995, 2000) and the DOP-H (Bastiaanse & Van Zonneveld, 2006) is the predictions they make regarding the performance of PWA in comprehension tasks. As a representational account, the TDH states that PWA miss the traces of the arguments and, hence, have to guess when they have to choose a picture corresponding to a semantically reversible sentence with non-base order of thematic roles, resulting in chance-level performance. The DOP-H (Bastiaanse & Van Zonneveld, 2006) does not make predictions in terms of chance, but suggests that the processing deficits will result in lower performance on semantically reversible sentences in which the arguments are not in base order (i.e. T-A order). A growing body of online processing data supports this latter prediction (Dickey et al., 2007; Hanne et al., 2011).

The introduction of online techniques in psycholinguistic and neurolinguistic studies has led to significant advancement in research. Studies with neuroimaging and eye-tracking (ET) techniques offer insight in real-time language processing to complement the behavioural offline data. This introduces two main advantages: First, online data permit the disambiguation of different processes involved in the same final result, and, therefore offering the possibility of reviewing linguistic symptomatology. Second, it offers the possibility to distinguish brain reactions accompanying correct answers from those accompanying incorrect choices, by comparing the real-time language processing of PWAs with healthy non-brain-damaged (NBD). This is relevant, because chance-level performance has been interpreted as the expression of guessing (e.g. Grodzinsky, 1986, 2000; see Burchert, Hanne, & Vasishth, 2013, for a review). Dickey et al. (2007), followed by Hanne et al. (2011), report evidence indicating that PWA do not guess. Dickey et al. (2007) studied the online comprehension of PWA with ET while comprehending sentences with *wh*-movement. They analysed the gaze-fixation patterns by convergence analysis and found that PWA showed a similar eye-movement pattern to that of NBD participants in the correct answers, but not in the incorrect answers. Hanne et al. (2011), using the same technology, tested comprehension in PWA speakers of German by comparing reversible sentences with SVO and OVS word orders. In line with Dickey et al. (2007), results revealed that the fixation patterns of PWA for correct and incorrect answers were qualitatively different. Thus, real-time language processing suggests that the chance-level performance of PWA is partly guided by normal patterns of language processing (see also Meyer, Mack, & Thompson, 2012).

The Visual World Paradigm (VWP) is based on the idea that language processing results in attention shifts across the visual display. Hence, cognitive processes involved in language comprehension are analysed by aligning the timing and pattern of eye-gaze fixations to potential referents displayed on the visual workspace (Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). This is feasible because eye fixations are time-locked with the continuous auditory stimuli within a margin of 200 ms (Matin, Shao, & Boff, 1993) and this tight link allows insight into real-time sentence processing by inferring from the gaze fixations on the visual stimuli. Healthy listeners fixate to the target referent after the auditory stimulus provides sufficient selectional restrictions to discard competitors. Interestingly, several studies have pointed out that they display an anticipatory behaviour in thematic role assignment while doing a sentence resolution task (Kamide, Altmann, & Haywood, 2003; Kamide, Scheepers, & Altmann, 2003; Knoeferle, Crocker, Scheepers, & Pickering, 2005). That is, they assign thematic roles to critical objects in the scene before the names of the objects have been mentioned in the auditory input. The building up of expectations about elements that have not yet been presented auditorily is due to the influence of the visual context information on incremental thematic role assignment, as has been shown for two case marking languages, German (Kamide, Scheepers, et al., 2003; Knoeferle et al., 2005) and Japanese (Kamide, Altmann, et al., 2003), although under different selective constraints. Altogether, this suggests that VWP is a useful framework to monitor the language comprehension deficits of PWA and, more specifically, their sensitivity towards word order and case morphology information when it comes to comprehending semantically reversible sentences. The use of the VWP thus seems to be a promising way to study how PWA parse grammatical functions in real time.

To sum up, sentence comprehension deficits in PWA are most noticeable in semantically reversible sentences with derived word order, but TDH (Drai & Grodzinsky, 2006a, 2006b; Grodzinsky, 1986, 1995, 2000) and DOP-H (Bastiaanse & Van Zonneveld, 2006) provide different explanations for the underlying causes of such impairments in PWA. The current study aims to further our insight into sentence processing in aphasia by analysing the effect of word order on sentence comprehension by PWA speakers of Basque, a free word order and head-final (SOV) ergative language with rich case morphology.

1.1. Linguistic background: Basque

Basque is a free word order language, with SOV as base order (De Rijk, 1969; Erdocia et al., 2009). The frequency of usage of each word order varies as quantified by means of written corpora analyses: SOV (56.8%); SVO (14.8%); OVS (13.8%); OSV (9.9%); VOS (3.3%); VSO (1.1%) (Aldezabal et al., 2003). Basque is a richly inflected language in which the inflected verb agrees with the subject, the direct object and the indirect object, which are all case marked. That is, the auxiliary verb presents polypersonal agreement with all the arguments of the sentence. This combination of agreement and morphological case is an infrequent typological pattern. Basque is an ergative language (Laka, 2006; Levin, 1983; Ortiz de Urbina, 1989). Hence, subjects of unaccusative verbs and objects of transitive verbs are morphologically identical (6–7), marked by zero case and called "absolutive", while the agentive subject of transitive clauses carries ergative case (-*k*) (1).

(6)	Txakurr-a-k	katu-a- Ø	harrapatu	du.
	dog-det-erg	cat-det-abs	caught	aux.has
	The dog has caught the cat.			
(7)	Txakurr-a- Ø	etorri	da.	
	dog-det-abs	arrived	aux.is	
	The dog has arrived.			

If a DP marked with absolutive case (Ø) appears at the beginning of a sentence, it can be initially interpreted as the subject of an intransitive/unaccusative verb (7), as a sentence-initial object with a null-subject subject (8), or as a topicalized object in a sentence with OSV word order (9) (see also Laka, 2012).

(8)	(Katu-a-k)	txakurr-a- Ø	harrapa-tu	du.
	(cat-det-erg)	dog-det-abs	catch-perf.	aux.has
	(The cat) has caught the dog.			
(9)	Txakurr-a-Ø	katu-a-k	harrapa-tu	du.
	dog-det-abs	cat-det-erg	catch-perf.	aux.has
	The cat has caught the dog.			

Note that the combination of the singular determiner (-*a*) and the ergative case marker (-*k*) yields a sequence that is homophonous with the plural absolutive marker (-*ak*) in Basque. Consequently, the first DP marked with -*ak* is temporarily ambiguous to the listener, since it may correspond either with a singular agent (6) or with a plural object (10).

(10) Katu-ak-Ø txakurr-a-k harrapa-tu ditu.
cat-det.pl-abs dog-det.sg-erg catch-perf. aux.has
The dog has caught the cats.

Inspired by this free word order property of Basque, Erdocia et al. (2009) compared the online processing of SOV-OSV sentences using self-paced reading and ERP techniques in healthy participants. Both sentence types were either morphologically unambiguous or ambiguous ergative DPs or plural absolutive DPs, as illustrated above in (10). The authors found that Basque speakers employed a "subject-first" processing strategy and consider the first DP as the subject of an unaccusative verb. Therefore, they systematically reanalysed OSV sentences at the second DP position. In addition, SOV word order imposed the lowest cognitive demands, as revealed by shorter reading times and a modulation of anterior negativities and P600 components. In another study Carreiras, Duñabeitia, Vergara, de la Cruz-Pavía, and Laka (2010) used the same ambiguous A/T morphological marking as Erdocia et al. (2009), but in subject/object relative clauses (henceforth SRC and ORC respectively) involving a temporal ambiguity between subject/object-gap that was resolved at the auxiliary verb of the main sentence. Because the ergative alienation of the language, subject relative structures arguments follow non-linear T-A order, while object relative structures have A-T argument order. Longer reading times and larger amplitudes in the P600 were interpreted by the authors as evidence that ORC are easier to process than SRC in Basque. Speakers deployed an agent-first strategy for the ambiguous sentence-initial DP, yielding lower processing demands for ORC. To sum up, converging evidence shows that healthy speakers of Basque use word order information to disentangle morphological ambiguities affecting the interpretation of thematic roles (for an overview, see: Laka & Erdocia, 2012).

1.2. Hypothesis and expectations

In the current study, the predictions of the TDH and the DOP-H on sentence comprehension processing in PWAs will be tested with behavioural data (i.e. accuracy and RT) and using eye fixations as an online measure of language processing.

The original version of the TDH (Grodzinsky, 1986, 1995, 2000) predicts that behaviourally the PWA group will perform above chance in the comprehension of sentences when the moved argument does not cross the verb in a hierarchical manner (11).

(11) $[_S\ NP_S\ [_{VP}\ NP_O\ V]]$

(12) $[_{S'} V_i\ [_S\ NP_S\ [_{VP}\ NP_O\ t_i]]]$

(13) $[_{S'}\ NP_{Oi}\ [_S\ NP_S\ [_{VP} t_i\ V]$

(14) $[_{S'} V_j\ [_{S'}\ NP_{Oi}\ [_S\ NP_S\ [_{VP}\ t_i\ t_j]$.[1]

In sentences with VSO word order (12), no argument has moved from its base position and therefore, PWA are expected to present above-chance accuracy. Conversely, in the OSV (13) and VOS (14) there is an additional crossing of the subject by the object and the use of the agent-first strategy will not result in the correct interpretation of the sentence. Therefore, chance-level accuracy is expected. Drai and Grodzinsky (2006a, 2006b) laid out some explicit predictions of the TDH for Germanic languages, also with SOV base word order, where they slightly modified the original TDH. According to the authors, the comprehension of passive sentences in Dutch is not impaired in PWA because in this construction the internal argument that becomes the subject of the sentence does not cross the lexical Verb (see Bastiaanse & Van Zonneveld, 2006, for a reply). If we assume that this restriction needs to be fulfilled to consider comprehension deficits, neither the OSV nor VOS word order should be impaired according to the TDH, since the object does not cross the Verb in any of these two constructions. Therefore, PWA speakers of Basque should correctly understand sentences presented in these conditions. Contrary to this, the DOP-H predicts that PWA will score higher in sentences with A/T linear order (i.e. SOV, VSO) than in sentences with T/A order (i.e. OSV, VOS). Therefore, these hypotheses on the underlying disorders make different predictions regarding the sentence processing patterns in PWA.

In addition, it should be noted that due to the pluri-personal character of verb agreement in Basque, and regardless of the sensitivity that PWA may have to the argument structure of the lexical verb, the auxiliary will also support thematic role information by means of agreement with the Agent and Theme of the sentence. That is, the argument structure of the verb will be over-specified at the auxiliary verb in both VSO and VOS conditions. A performance pattern of preserved comprehension in the VSO condition and impaired abilities in the comprehension of VOS support that even when thematic role assignment does not require full access to argument structure information because thematic roles are unambiguously marked by case morphology, there is an impaired assignment of thematic roles onto the DPs. Contrary to this, preserved comprehension of VOS sentences and impaired comprehension in the OSV condition would indicate that PWA assign thematic roles correctly to the DPs when those are offered beforehand by means of agreement morphology on the verb, but they do present impairment in reanalysis processes in verb-final constructions.

TDH does not make explicit predictions about RTs. The DOP-H predicts that for PWA sentences with derived word order (i.e. OSV, VSO, VOS) will take longer to process due to the increased processing load.

Regarding gaze data, distinct patterns are predicted by TDH and DOP-H. The former predicts that gaze-fixation patterns of the sentences for which the PWA have to guess (i.e. OSV and VOS) will be qualitatively different from those of healthy participants, whereas the fixation pattern and timing-window are expected to be similar to those for control participants in conditions with above-chance accuracy (i.e. SOV and VSO). The DOP-H predicts that trials eliciting correct and incorrect answers in PWA should correspond to qualitatively different fixation patterns. Moreover, it is expected that the slowdown of linguistic processing in PWA will cause a temporal delay from the auditory presentation of the stimuli until the fixation to the visual target, as compared to NBD participants.

2. Methods

The study obtained the approval of the Basque Clinical Research Ethics Committee (CEIC-E). All participants received written and oral information about the study, rights and implications of their participation, and signed an informed consent form.

2.1. Participants

Eight individuals with aphasia (mean age 66.37 years; SD= 14.37; range= 43–83; male/female = 6:2) met the inclusion criteria to take part in this study. They were all L1Basque–L2Spanish bilingual speakers[2] and had experienced a left hemisphere stroke 3–24 months prior to the study. They were right-handed pre-morbidly, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). The NBD group was composed of eight L1Basque–L2Spanish bilingual speakers without any history of neurological or sensory impairments. They were matched on age range, education level and literacy language with the clinical group (mean age 62.25 years; SD = 13.31; range = 38–80; male/female = 5:3). They all demonstrated normal or corrected-to-normal vision and hearing.

The PWA were Basque–Spanish bilingual speakers whose native language was Basque. They had acquired Spanish at an early age (2–5 years). They were all literate only in Spanish, their language of instruction at school, with the exception A4 who was literate in Basque as well, having used both Spanish and Basque as languages of instruction at school. See Appendix 1 for detailed individual data.

Prior to their participation in this study, the PWA had been assessed with the Cognitive Neuroscience Laboratory language screening battery (CNL; Chialant, 2000; adapted to Basque by Erdocia, Santesteban, & Laka, 2003) for working memory using the digit-span task (Wechsler adult intelligence scale-III; Wechsler, 1997), auditory discrimination and comprehension abilities. In the latter test, both word (i.e. nouns and verbs) and sentence comprehension were assessed using picture-matching tasks. Lexical materials were controlled for imageability, animacy as well as frequency; sentences included simple and embedded declaratives presented in both base word order (SOV) and a non-base order (OSV). The sentences were counterbalanced for semantic reversibility, number/person agreement and number of arguments required by the verb, and were marked with ergative, absolutive and dative case morphology, when necessary.

As shown in Appendix 2, all eight PWAs had preserved word comprehension abilities for both verbs and nouns, and impaired sentence comprehension abilities. The latter was characterised as chance or below chance performance in the comprehension of semantically reversible sentences in at least one condition (i.e. base SOV vs. derived OSV word order). Visual neglect was excluded as a cause of poor performance among all participants using the Behavioural Inattention Test (BIT; Wilson, Cockburn, & Halligan, 1987).

Since no normalised assessment tools are available for PWA speakers of Basque, we analysed samples of spontaneous speech to characterise the clinical participants as non-fluent based on the criteria described below. The samples were taken through spontaneous conversation and elicited language while participants were describing such pictures as the *Cookie Theft* (The Boston Diagnostic Aphasia Examination; Goodglass, Kaplan, & Barresi, 2000) or *Flood Rescue* (Olness, 2006). The analysis was focused on the Mean Length Utterance (MLU), finiteness, grammaticality and speed (i.e. number of words per utterance) in samples of 200 words, unless otherwise indicated. Detailed results are available in Appendix 3. Subsequently these samples were compared with the spontaneous language of 10 native Basque speakers matched by age range, dialect and gender using *Ahotsak Ahozko Tradiziozko Korpusa* (*Traditional Oral Language Corpus Ahotsak*; Badihardugu Euskara Elkartea, 2008; see Appendix 4). Although the sample materials have not been recorded under similar circumstances, we believe that they offer a rather good picture of language production handicaps shown by the PWA included in the current study.

2.2. Design and materials

Materials for the ET study consisted of single sentences presented auditorily, simultaneously with the presentation of pairs of pictures. One of the pictures depicted the action described by the spoken sentence, while the other showed the same action with an A-T reversal (see Figure 1). There were 176 trials consisting of 80 experimental items, 80 fillers and 16 practice items.

2.2.1. Linguistic stimuli

Twenty-two transitive verbs were selected to create the items. Each verb was complemented with two animate, singular DPs to create declarative sentences in the following word orders (a) SOV; (b) OSV; (c) VSO and (d) VOS. The assignment of the A-T roles to the DPs in each pair of DPs was randomised and balanced within the four conditions. Hence, each DP was the Agent of the sentence in two out of four conditions. The filler stimuli were created using 22 unaccusative verbs in combination with a single animate DP. In addition, a temporal adverb functioning as an adjunct was added to keep sentence length between target and filler stimuli constant. Filler stimuli were also presented in the four word orders described above, although in this case the adjunct (i.e. temporal adverb) replaced the position of the grammatical object in the sequence. All arguments of both target and filler sentences were highly imageable, had 4 syllables and comparable lemma frequency (<1000 words/million) as extracted from the *Euskal Hiztegiaren Maiztasun Egitura* ("The Frequency Structure of the Basque Dictionary"; Acha, Laka, Landa, & Salaburu, 2014).

In the semantically reversible target sentences, the Agent was overtly marked with the ergative case marker attached to the DP (*-k*), while the Theme was zero-marked for absolutive case, as illustrated in (15–18) below; all sentences mean "the lady has combed the girl ('s hair)".

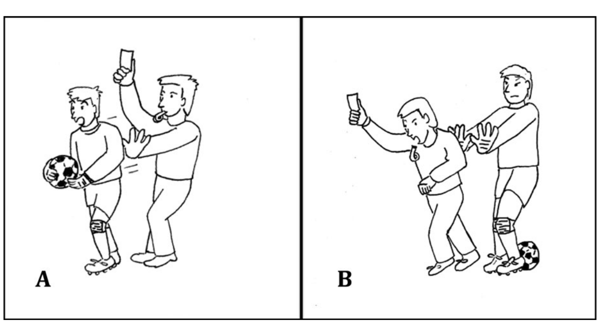

Figure 1. Sample visual display. Target stimulus (SOV): "Arbitroak atezaina bultzatu du" (The referee has pushed the goalkeeper). (A) Target picture; (B) foil.

(15)	Subject – object – verb (– aux)			
	Andere-a-k	neskato-a-Ø	orraz-tu	du
	lady-det-erg	girl-det-(abs)	comb-perf.	aux.has
(16)	Object – subject – verb (– aux)			
	Neskato-a-Ø	andere-a-k	orraz-tu	du
	girl-det-abs	lady-det-erg	comb-perf.	aux.has
(17)	Verb (– aux) – subject – object			
	Orraz-tu	du	andere-a-k	neskato-a-Ø
	comb-perf.	aux.has	lady-det-erg	girl-det-abs
(18)	Verb (– aux) – object – subject			
	Orraz-tu	du	neskato-a-Ø	andere-a-k
	comb-perf.	aux.has	girl-det-abs	lady-det-erg

As is the case in ergative languages, the object of the transitive verb carries the same morphological marker (Ø) as the subject of unaccusative verbs. As shown by Erdocia et al. (2009), Basque listeners use a subject-first strategy to resolve this syntactic ambiguity; thus, they assume that the first DP is the subject of a transitive verb. The processer detects that parsing is incorrect when it reaches the subject marked with the ergative -k as the second DP, and it is forced to reanalyse the sentence. One of the points of interest in the present study was to investigate whether Basque-speaking PWA are able to revise their initial grammatical parsing, and hence, reanalyse the sentences (i.e. OSV). To maintain the syntactic ambiguity filler items with unaccusative verbs were combined with the target stimuli.

Additionally, two of the experimental conditions, VSO and VOS, were selected to test the sensitivity to verb morphology in PWA. We wanted to see whether PWA process verb agreement morphology and, if so, whether this overwrites the impact of word order in the comprehension deficits. Recall that in Basque the inflected verb agrees in case, number and person with all arguments of the sentence, and therefore, the listener may disentangle thematic roles resorting to agreement morphology, with the support of the visual stimuli, as soon as the verb and the first DP are presented (see Ros, Santesteban, Fukumura, & Laka, 2015). In such a case, incremental thematic role assignment is expected from the offset of the first DP, without the need to process the subsequent case markers affixed to the second argument (as shown in Kamide, Altmann, et al., 2003; Kamide, Scheepers, et al., 2003; Knoeferle et al., 2005 with NBD participants).

In the filler sentences, the subjects were not Agents but Themes, zero-marked for absolutive case, with unaccusative verbs (see 19–22). Hence,

Filler sentences:

(19)	Dantzari-a- Ø	bapatean	argaldu	da
	dancer-det-abs	suddenly	become.thin	aux.has
(20)	Bapatean	dantzari-a-Ø	argaldu	da
	Suddenly	dancer-det-abs	become.thin	aux.has
(21)	Argaldu	da	dantzari-a- Ø	bapatean
	become thin	aux.has	dancer-det-abs	suddenly
(22)	Argaldu	da	bapatean	dantzari-a- Ø
	become thin	aux.has	suddenly	dancer-det-abs
	The dancer has suddenly become thin.			

Sentences were recorded by a female native speaker of Basque in a soundproof booth (IAC) using a digital microphone (audio-technica AT4022a). Recordings were normalised using Audacity (v.2.0.3), a cross-platform sound editor. A similar constant prosodic contour was used across all sentence conditions to avoid giving cues biasing one or another interpretation (Weber, Grice, & Crocker, 2006). A rather slow speech rate of 3.57 syllables per second was used, which is still within the parameters for normal speech (3–6 syllables/sec; Levelt, 2001). Since the constituents of the sentences were matched on length (i.e. four syllables/constituent) and speech rate, all constituents and sentences had a duration of 1.12 and 3.36 sec respectively across all conditions. This fact allowed the subsequent analysis of the longitudinal data (i.e. gaze data) in time windows matched by length across constituents and stimuli.

2.2.2. Visual stimuli

Visual stimuli consisted of 88 black-and-white line drawings divided into 44 pairs separated by a black vertical line in the middle of the screen. Each pair of pictures depicted the same reversible action differing in the role of A/T. A sample of the visual display is presented in Figure 1. The pictures were approximately 15 × 15 cm. and the elements on them were presented at a similar size, while keeping the proportional differences between different elements in the real world (e.g. a child is smaller than an adult). The pictures were controlled for name and comprehension agreement in a norming study with 20 healthy participants. This group was comprised of 20 L1Basque–L2Spanish bilingual speakers (mean age 31.7 years; SD = 2.55; range = 27–38; male–female = 10:10). In the normalisation process, the visual stimuli were presented on a 14.1″ screen, with a resolution of 1280 × 800. To test name agreement, the picture was shown and the verb was given to the participants in order to elicit a sentence describing the picture. Attention was focused on the use of nouns and assignment of the A-T roles in the answer provided by the participants. The use of synonyms or substitution of the nouns was counted as correct as long as they represented the same referent (e.g. the nouns *ama* "mother" and *anderea* "lady") and showed unambiguous recognition of the depicted elements. For comprehension agreement, each pair of pictures was shown to the participants simultaneously with an auditory presentation of a sentence. The latter always corresponded to the canonical sentence word order (SOV) and referred to one of the two pictures randomly. Participants were instructed to point to the picture that best depicted the auditory stimuli. After implementing the necessary changes, an agreement of 90.90% and 96.13% was reached in naming and comprehension normalisation, respectively.

After normalisation, the order of the visual stimuli was pseudo-randomised for the experimental stage based on two criteria. First, the position of the target item on the screen was pseudo-randomised in order to avoid a preference in selecting the drawing depending on its location (i.e. left/right) on the visual display. No more than two target stimuli were displayed in a row on the same side of the screen. Secondly, the direction in which the action was performed in the picture was randomised in order to avoid preferences in left-to-right scanning strategy (Scheepers & Crocker, 2004).

2.3. Procedure

The order of both target and filler stimuli was randomised and divided into 4 blocks of 40 items for presentation. In each experimental session, two blocks of items were administered, preceded by the presentation of eight trial items. No more than two experimental items from the same condition were presented in a row. The experiment was conducted using E-prime 2.0 software with extensions for Tobii 2.1 (Psychology Software Tools, Pittsburgh, PA).

The visual stimuli were presented on a screen of 23 inches with a resolution of 1280 × 720, and the auditory stimuli were played through stereo headphones (Sony, MDR-XD100). Gaze movements were monitored using a Tobii T120 remote portable eye-tracker (sampling rate: 120 Hz) located below the screen. Participants were placed at 60–70 cm distance from the screen, with a visual angle under 15° (max. allow 35°).

Each of the four blocks of stimuli was preceded by a short calibration of the eye-tracker. Such calibration was performed to re-assess the eye position and to ensure that the device correctly detected the eye-gaze of the participants. The participants were required to fixate into five calibration points that appeared in sequence along the screen. Once the initial calibration had been performed successfully, each experimental session started by providing written instructions on the laptop screen to describe the experimental task. The same instructions were verbally explained to all participants before running the experiment.

The participants performed a picture-matching task. Each trial started with the presentation of a fixation smiley face in the centre of the screen. The participants needed to fixate on the image for 250 ms before the presentation of the stimuli was executed. This measure was taken to ensure that the participants did not have a fixation bias at the onset of the stimuli. Subsequently, the visual stimulus was presented on the screen. After

1000 ms of previsualisation, the auditory stimulus was presented. The participants' task was to select the picture that best corresponded to the meaning of the presented sentence by pressing specific buttons on the keyboard using the left hand. Trials without answer within an 8000 ms time window from the offset of the sentence were registered as "no answer" and the next stimulus was presented automatically.

Non-answered trials were excluded from the data analysis, corresponding to the 2.07% of the total target data. Only fixations lasting more than 90 ms (11 data points) were included in the data analysis to avoid blinks and saccades from interfering in the results. In addition, it was checked that there was no trial answered before 500 ms from the onset of the auditory presentation since such answers may be due to accidental button press rather than to a conscious answer. Gaze-fixation data was switched 200 ms to correct the delay of the gaze fixation in relation to the auditory stimuli (Matin et al., 1993).

3. Data analysis

In addition to standard descriptive statistics, Generalised Linear Mixed-effects Models (GLMM) and Linear Mixed-effects Models (LMM) were used to identify determinants of sentence comprehension across behavioural and gaze data (i.e. GLMMs for the accuracy data, LMMs for the RT and gaze data). (G)LMM is a statistical technique assessing the linear effect of both fixed-effects terms (i.e. regression coefficients) and random-effects terms in a single model. Thus, it simultaneously considers repeatable covariates and the unexplained variation introduced by a specific selection of subject and linguistic stimuli, which are treated as samples from the population of interest. (G)LMMs are suitable to analyse longitudinal and repeated measures studies for a number of reasons. It has been shown to accommodate missing data satisfactorily and to be robust towards outliers (Verbeke & Molenberghs, 2000), which are crucial properties to take into account in the analysis of reduced sample sizes. The difference between a GLMM and LMM is that in the former case, the dependent variable is binary (with 1 indicating a correct answer, and 0 indicating an incorrect answer) and the estimates have to be interpreted with respect to the logit scale (i.e. the log of the odds of observing a correct answer). A positive estimate on this scale indicates that (an increasing value of) the predictor has a positive effect on the probability of observing a correct answer. Similarly, a negative estimate indicates a negative effect on the probability of observing a correct answer. In the latter case (i.e. LMM), the dependent variable is numerical.

Empirical model building was conducted with the offline (i.e. accuracy and RT) and online (i.e. gaze fixation) data. For that, separate (G)LMMs were fitted by progressively introducing random effects, fixed effects and correspondent interactions. Random slopes were not included in the models due to convergence problems, likely due to the limited sample size. Instead, nested random intercepts were used to account for the variability of the subjects and stimuli in relation to some explanatory factorial predictors (e.g. a random intercept for the combination of subject and condition). Model comparison was conducted based on the Akaike's Information Criterion (AIC; Akaike, 1974), with a reduction in AIC of 2 indicating a better fitting model (taking into account the complexity of the models). Models with the lowest AIC were kept. When comparing models with a different fixed-effects structure, these were fitted using maximum likelihood estimation (ML). Restricted maximum likelihood estimation (REML; Harville, 1974; Patterson & Thompson, 1971) was used when comparing random effects and for our final model (for a detailed review, see McCulloch & Searle, 2000; Verbeke & Molenberghs, 2000). Subsequently, least square means (LSMeans) and 95% confidence intervals (95% CI) were calculated and pairwise comparisons were carried out with a Tukey correction. Effects are considered significant at the $p < 0.05$ level, unless otherwise indicated. The RT and gaze-fixation data were log transformed because skewed distributions. The numerical predictors Age and Trial number were centred.

In the case of the RT data, the empirical (i.e. best) model did not fully cover the research questions of the study. Therefore, a second model was fitted specifically according to our hypothesis, where the inclusion of fixed-effect predictors was predetermined, and the best random-effects structure was assessed via AIC comparison. The analysis was conducted using R Statistic software (R Core Team, v.3.2.3.) using the *lme4* package (Bates, Mächler, Bolker, & Walker, 2015).

4. Results

4.1. Comprehension accuracy

General descriptives of accuracy scores at group level are provided in Table 1. The NBD group did not perform at ceiling level in either of the sentence types, offering a fully sensitive measure to differentiate among the conditions and between groups. See Appendix 5 for individual participant scores.

A logit link function was used for the GLMM. The final model obtained for the accuracy data contained two-way interactions for group and condition as fixed

Table 1. Comprehension accuracy and standard error (SE) as a function of group and sentence condition.

	Accuracy % (SE)	
Condition	PWA	NBD
SOV	75.81 (3.47)	91.19 (2.25)
OSV	45.80 (4.01)	90.56 (2.32)
VSO	71.14 (3.72)	93.71 (1.93)
VOS	52.28 (4.05)	87.97 (2.59)

effects, and stimuli and subject variables as random-effects. In addition, the analysis highlighted that the strength of the condition was different between subjects; thus, a nested random effect (i.e. for each combination of subject and condition) was added to enable a more precise estimation of the effect of sentence condition in each subject.

There was a significant interaction between group and sentence condition. Overall, the PWA group performed significantly less accurately than NBDs across all sentence conditions. Thus, they presented difficulties comprehending sentences in both canonical word order (i.e. SOV) and non-canonical word order (i.e. OSV, VSO and VOS), although under different significance levels, as presented in Table 2.

Within-group comparisons in the PWA group uncovered significant differences in the comprehension abilities across sentence conditions. In this group, stimuli were significantly better comprehended when presented in conditions SOV and VSO than in OSV and VOS (see Table 3). The NBD group did not present accuracy differences across sentence conditions.

4.2. Response RT

Two separate LMMs were fitted for the RT data. The first one was built following the empirical procedure described previously, where variables that better explained the observed data were included in the model. The second one was a hypothesis-driven model that included the variables required to answer the research question of the current study, also including predictors which were excluded (due to lack of explanatory power) from the other model (See Figure 2 and Table 4 for descriptive statistics).

The empirical model consisted of three-way interactions between the group, sentence condition and trial number, in addition to random intercepts for subject and stimulus and the nested random intercepts of subject with condition and stimulus with condition (i.e. specified in *lmer* as "(1|Subject/Condition) + (1|Stimulus/Condition)"). As presented in Table 5, this model showed no significant RT differences between groups across any of the conditions. Pairwise comparisons were conducted by condition within each group and the results are presented in Table 6. The aphasic group did not show differences in RTs in the different conditions, but NBDs showed significantly longer RTs in OSV and VOS conditions when compared to SOV (base order of the arguments), but not when compared to VSO condition (base order of the arguments).

Table 2. Comparison of response accuracy between groups across sentence conditions.

	Group	LSMeans (95% CI)	*β*	SE	*z*-Ratio	*p*
SOV	NBD	2.65 (1.80–3.51)	1.315	0.564	2.328	0.0199
	PWA	1.34 (0.60–2.08)				
OSV	NBD	2.57 (1.73–3.42)	2.736	0.553	4.944	<0.0001
	PWA	−0.15 (−0.87–0.55)				
VSO	NBD	3.00 (2.09–3.91)	1.946	0.583	3.334	0.0009
	PWA	1.05 (0.32–1.79)				
VOS	NBD	2.23 (1.42–3.03)	2.102	0.534	3.932	0.0001
	PWA	0.12 (−0.58–0.84)				

Note: Significance level $p < 0.05$.

Table 3. Comprehension accuracy differences between sentence conditions in PWA and NBD groups.

		OSV				VSO				VOS			
	LSMeans (95% CI)	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*
PWA group													
SOV	−0.15 (−0.87–0.55)	−1.502	0.360	−4.170	0.0002	−0.286	0.344	−0.829	0.8403	−1.217	0.356	−3.419	0.0035
OSV	1.34 (0.60–2.08)	–	–	–	–	1.216	0.359	3.384	0.0040	0.285	0.368	0.774	0.8658
VSO	0.12 (−0.58–0.84)	–	–	–	–	–	–	–	–	−0.931	0.355	−2.621	0.0435
VOS	1.05 (0.32–1.79)	–	–	–	–	–	–	–	–	–	–	–	–
NBD group													
SOV	2.57 (1.73–3.42)	−0.081	0.468	−0.174	0.9981	0.347	0.447	0.777	0.8649	−0.428	0.495	−0.864	0.8233
OSV	2.65 (1.80–3.51)	–	–	–	–	0.429	0.451	0.949	0.7781	−0.346	0.499	−0.693	0.8998
VSO	2.23 (1.42–3.03)	–	–	–	–	–	–	–	–	−0.775	0.478	−1.620	0.3671
VOS	3.00 (2.09–3.91)	–	–	–	–	–	–	–	–	–	–	–	–

Note: Significance level $p < 0.05$.

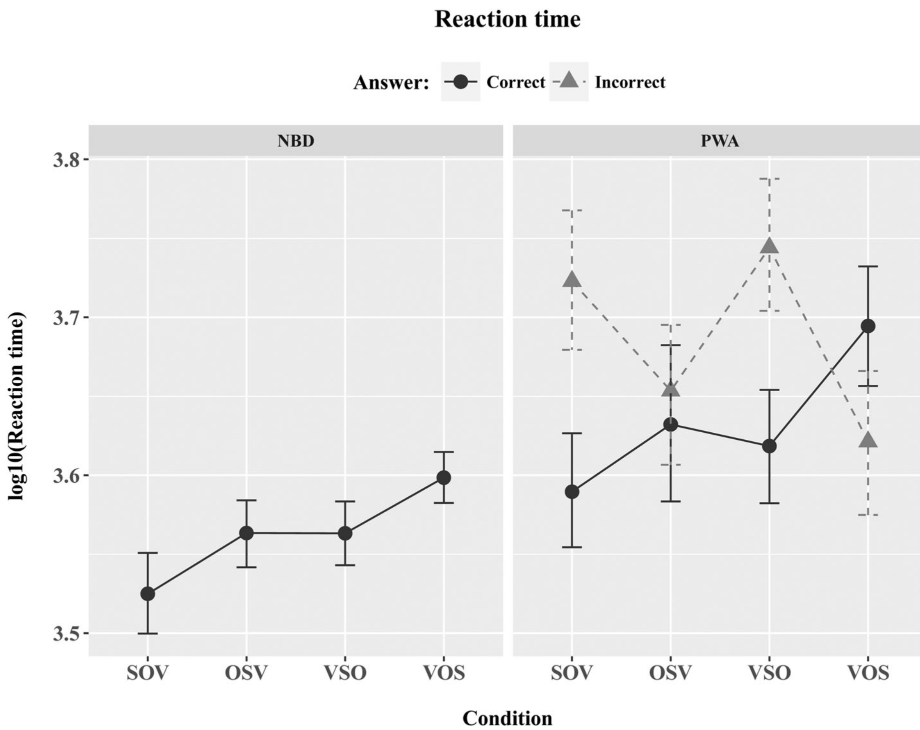

Figure 2. Log transformed RTs as a function of group, sentence condition and correctness of the response.

Table 4. Mean RT and SE as function of group and sentence condition.

	Mean RT (SE) in ms	
Condition	PWA	NBD
SOV	4635.64 (161.96)	3619.69 (102.58)
OSV	4898.85 (174.77)	3953.67 (100.91)
VSO	4921.31 (168.28)	3891.77 (107.44)
VOS	5022.03(173.55)	4125.95 (90.58)

Table 5. RT differences between groups across sentence condition.

		LSMeans (95% CI)	β	SE	z-Ratio	p
SOV	NBD	8.11 (7.86–8.36)	−0.233	0.163	−1.433	0.1719
	PWA	8.35 (8.10–8.59)				
OSV	NBD	8.23 (7.98–8.48)	−0.168	0.163	−1.031	0.3184
	PWA	8.40 (8.15–8.65)				
VSO	NBD	8.22 (7.97–8.47)	−0.216	0.163	−1.326	0.2042
	PWA	8.43 (8.19–8.68)				
VOS	NBD	8.29 (8.04–8.54)	−0.145	0.163	−0.893	0.3857
	PWA	8.43 (8.18–8.68)				

Note: Significance level $p < 0.05$.

Moreover, there was a significant interaction between group, condition and trial number. That is, NBD participants became faster along the experiment, but this was not the case for the PWA group. Detailed information is provided in Table 7. The PWA group did not show an effect of trial number across any of the sentence conditions, while in the NBD group trial number significantly influenced both SOV and OSV conditions, but not VSO and VOS conditions.

The hypothesis-driven model consisted of a three-way interaction between group, sentence condition and accuracy of the response as fixed effects, in addition to the same random-effects structure as for the exploratory model. The results of the comparisons between the groups and sentence conditions were close to the previous model and results are reported in Tables 8–9. The main interest of developing this new model was to test whether the accuracy of the answers had an effect on the RT of the participants. We compared correct and incorrect answers solely for the PWA group, since the number of incorrect answers within the NBD group was too small. As presented in Table 10, the results showed that the accuracy of the answer (i.e. correct, incorrect) did not have any effect on the RT.

4.3. Gaze data analysis

To conduct the gaze data analysis, the difference in the proportion of fixations between the correct and incorrect visual stimuli was computed from the onset of the first argument (ROI1) to 1120 ms after the offset of the third argument (ROI4) (see Figure 3). Therefore, a temporal frame of 4480 ms was analysed, divided into four windows (i.e. ROIs). As described in the method section, each of the four ROIs had the same length across all stimuli and conditions (i.e. 1120 ms). ROIs 1, 2 and 3 corresponded to the first, second and third constituents of the sentence, while ROI 4 corresponded to

Table 6. RT differences between sentence conditions in PWA and NBD groups.

	LSMeans (95% CI)	OSV β	OSV SE	OSV z-Ratio	OSV p	VSO β	VSO SE	VSO z-Ratio	VSO p	VOS β	VOS SE	VOS z-Ratio	VOS p
PWA group													
SOV	8.35 (8.10–8.59)	−0.050	0.042	−1.207	0.6252	−0.089	0.042	−2.101	0.1652	−0.087	0.042	−2.076	0.1738
OSV	8.40 (8.15–8.64)	–	–	–	–	−0.038	0.042	−0.914	0.7975	−0.036	0.041	−0.876	0.8171
VSO	8.43 (8.19–8.68)	–	–	–	–	–	–	–	–	0.002	0.042	0.048	1.0000
VOS	8.43 (8.19–8.68)	–	–	–	–	–	–	–	–	–	–	–	–
NBD group													
SOV	8.11 (7.86–8.36)	−0.116	0.041	−2.786	0.0360	−0.106	0.042	−2.547	0.0640	−0.175	0.041	−4.203	0.0006
OSV	8.23 (7.98–8.48)	–	–	–	–	0.009	0.041	0.228	0.9958	−0.059	0.041	−1.421	0.4919
VSO	8.22 (7.97–8.47)	–	–	–	–	–	–	–	–	−0.068	0.041	−1.642	0.3641
VOS	8.29 (8.04–8.54)	–	–	–	–	–	–	–	–	–	–	–	–

Note: Significance level $p < 0.05$.

Table 7. Trial number effect on the RT across sentence conditions in PWA and NBD groups.

		LSMeans (95% CI)	β	SE	z-Ratio	p
PWA group						
SOV	≈1	8.37 (8.12–8.63)	0.053	0.074	0.716	0.4751
	≈80	8.32 (8.06–8.58)				
OSV	≈1	8.42 (8.16–8.67)	0.038	0.073	0.524	0.6009
	≈80	8.38 (8.12–8.63)				
VSO	≈1	8.45 (8.19–8.72)	0.038	0.074	0.522	0.6022
	≈80	8.42 (8.16–8.67)				
VOS	≈1	8.44 (8.19–8.70)	0.022	0.077	0.297	0.7671
	≈80	8.42 (8.16–8.68)				
NBD group						
SOV	≈1	8.30 (8.04–8.56)	0.373	0.072	5.143	<0.0001
	≈80	7.93 (7.67–8.19)				
OSV	≈1	8.33 (8.07–8.58)	0.198	0.068	2.888	0.0043
	≈80	8.13 (7.87–8.39)				
VSO	≈1	8.25 (8.00–8.51)	0.072	0.069	1.045	0.2975
	≈80	8.18 (7.93–8.44)				
VOS	≈1	8.33 (8.07–8.58)	0.078	0.073	1.059	0.2905
	≈80	8.25 (7.99–8.51)				

Notes: ≈1 = Initial trials; ≈80 = final trials. Significance level $p < 0.05$.

Table 8. Hypothesis-driven model. RT differences between groups across sentence conditions.

		LSMeans (95% CI)	β	SE	z-Ratio	p
SOV	NBD	8.10 (7.85–8.35)	−0.269	0.163	−1.641	0.1201
	PWA	8.37 (8.12–8.62)				
OSV	NBD	8.29 (8.04–8.54)	−0.105	0.163	−0.645	0.5282
	PWA	8.40 (8.15–8.64)				
VSO	NBD	8.26 (8.00–8.51)	−0.184	0.165	−1.117	0.2800
	PWA	8.44 (8.19–8.69)				
VOS	NBD	8.27 (8.02–8.52)	−0.162	0.162	−1.000	0.3325
	PWA	8.43 (8.18–8.68)				

Note: Significance level $p < 0.05$.

the post-offset silence. Missing gaze data motivated by answers provided before the offset of ROI4 (i.e. RT < 4480 ms) were treated by logical imputation based on the accuracy of the response. Positive values indicated a margin of difference of fixations towards the correct picture: negative values indicated the inverse pattern. For hypothesis testing, an LMM was fitted with a four-way interaction between the group, sentence condition, ROI and accuracy of the response as fixed effects. In addition, random intercepts for subject and stimuli were included, as well as nested random intercepts for subject/stimuli together with condition and accuracy.

The analysis focused on four distinct aspects. First, we compared the proportion of fixations across ROIs between sentence conditions SOV and OSV, and between sentences conditions VSO and VOS. The analysis was conducted separately as a function of group and response accuracy.[3] This analysis aimed to compare the proportion of gaze fixations into the target picture during the presentation of the Subject, Object, Verb and post-offset region in verb-final (i.e. SOV and OSV) and verb-initial (i.e. VSO and VOS) sentences. Pairwise comparisons of the correctly answered trials in NBD and PWA groups are provided in Tables 11 and 12, respectively. The analysis of the gaze-fixation pattern of PWA in the incorrectly answered trials is provided in Table 13. The significance level was set to an alpha level of 0.003 with a Bonferroni correction for multiple comparisons (i.e. 0.05/16).

In the correctly answered trials, the proportion of fixations towards to target picture during the auditory presentation of the subject did not vary between SOV and OSV conditions, either in NBD or PWA groups. In contrast, the proportions of fixations towards the target picture while auditorily presented with the object were greater in SOV (i.e. ROI2) than in OSV (i.e. ROI1) in both PWA and NBD groups. The results are in a similar vein in pairwise comparisons across ROIs between VSO and VOS sentence conditions. Gaze-fixation proportion towards to the target picture during the auditory presentation of the subject did not vary between VSO (i.e. ROI2) and VOS (i.e. ROI3) in either PWA or NBD groups, whereas it did during the auditory presentation of the object. Both PWA and NBD groups fixated more significantly into the target picture while presented with the object in VSO (i.e. ROI3) than in VOS (i.e. ROI2) sentence condition. One-by-one comparison of the ROIs attending to their position into the sentence did not show differences between verb-final (SOV and OSV) nor verb-initial (VSO and VOS) conditions either in NBD or in PWA groups. That is, proportion of fixations in ROI1 in SOV (i.e. subject position) and OSV (i.e. object position)

Table 9. Hypothesis-driven model. PWA and NBD groups: RT differences between sentence conditions.

	LSMeans (95% CI)	OSV *β*	OSV SE	OSV *z*-Ratio	OSV *p*	VSO *β*	VSO SE	VSO *z*-Ratio	VSO *p*	VOS *β*	VOS SE	VOS *z*-Ratio	VOS *p*
PWA group													
SOV	8.37 (8.14–8.60)	−0.027	0.043	−0.636	0.9200	−0.071	0.044	−1.610	0.3792	−0.063	0.043	−1.446	0.4756
OSV	8.40 (8.17–8.63)	–	–	–	–	−0.044	0.043	−1.022	0.7375	−0.035	0.042	−0.839	0.8355
VSO	8.44 (8.21–8.67)	–	–	–	–	–	–	–	–	0.008	0.043	0.202	0.9970
VOS	8.43 (8.20–8.66)	–	–	–	–	–	–	–	–	–	–	–	–
NBD group													
SOV	8.10 (7.86–8.33)	−0.191	0.055	−3.435	0.0042	−0.156	0.059	−2.628	0.0453	−0.169	0.053	−3.139	0.0109
OSV	8.29 (8.06–8.53)	–	–	–	–	0.034	0.059	0.589	0.9353	0.022	0.053	0.413	0.9762
VSO	8.26 (8.02–8.49)	–	–	–	–	–	–	–	–	−0.012	0.057	−0.223	0.9961
VOS	8.27 (8.04–8.50)	–	–	–	–	–	–	–	–	–	–	–	–

Note: Significance level $p < 0.05$ with Tukey's correction for multiple comparison.

Table 10. Hypothesis-driven model. PWA group: RT differences between correct and incorrect responses.

		LSMeans (95% CI)	*β*	SE	*z*-Ratio	*p*
SOV	I	8.41 (8.15–8.66)	0.078	0.043	1.782	0.0751
	C	8.33 (8.08–8.58)				
OSV	I	8.40 (8.15–8.65)	0.000	0.039	0.024	0.9813
	C	8.40 (8.15–8.65)				
VSO	I	8.46 (8.21–8.71)	0.041	0.043	0.957	0.3386
	C	8.42 (8.17–8.67)				
VOS	I	8.40 (8.15–8.65)	−0.060	0.039	−1.518	0.1292
	C	8.46 (8.21–8.71)				

Notes: C = correct answers; I = incorrect answers. Significance level $p < 0.05$.

did not differ, neither in ROI2 (i.e. object in SOV vs. subject in OSV), ROI3 (i.e. Verb in SOV vs. in OSV) and ROI4 (i.e. post-off silence in SOV vs. OSV). The same results are extensible to VSO and VOS conditions. In the incorrectly answered trials by PWA, proportions of fixations across sentence conditions are indistinguishable (see Table 13).

Second, the linear predictor of the gaze-fixation data was compared with zero in each sentence condition and ROI to uncover in what ROI the fixation proportion exceeded what is expected by chance. That is, it allows identifying the time window in which listeners have visually resolve the sentence, thus they have committed one or other sentence interpretation. This analysis was conducted separately as a function of group and response accuracy, as shown in Table 14. In the correctly answered trials, both PWA and NBD participants showed a

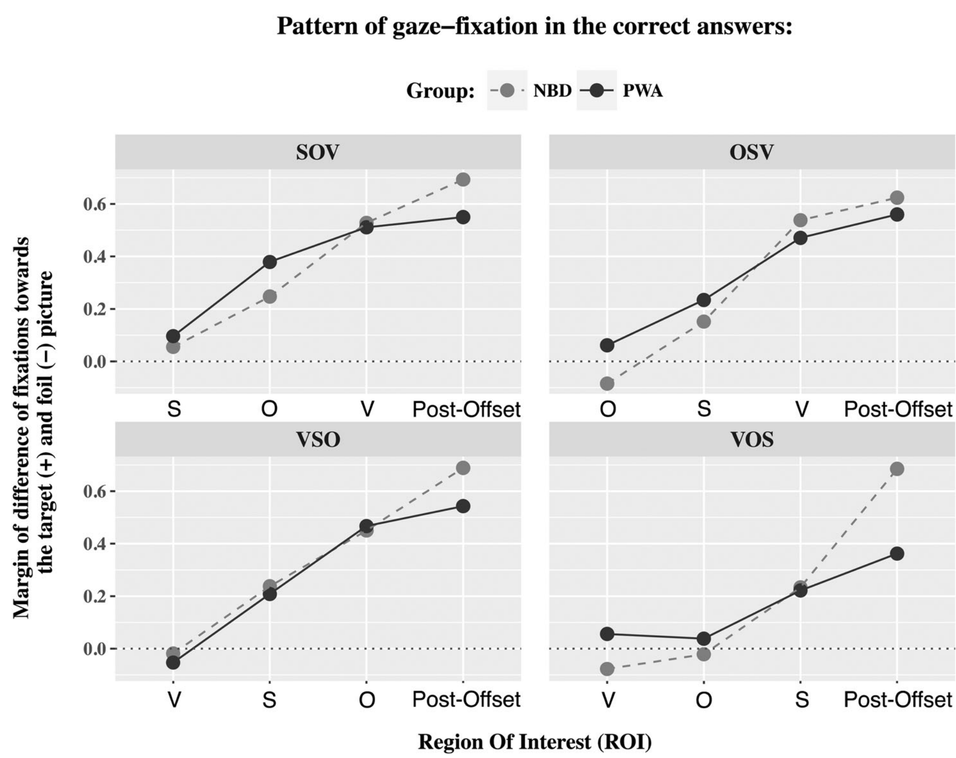

Figure 3. Gaze-fixation patterns across the visual stimuli during the auditory presentation of the sentence. Between-group comparison in the correct answers.

Table 11. Comparison of proportion of gaze fixations between verb-final (SOV and OSV) and verb-initial (VSO and VOS) conditions across ROIs, in correctly answered trials in NBD group.

	OSV															
	ROI1				ROI2				ROI3				ROI4			
SOV	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*
ROI1	0.386	0.303	1.274	0.2026	−0.326	0.303	−1.076	0.2820	−1.515	0.303	−4.990	<0.0001	−1.369	0.303	−4.507	<0.0001
ROI2	0.981	0.303	3.236	0.0012	0.269	0.303	0.888	0.3746	−0.920	0.303	−3.030	0.0024	−0.774	0.303	−2.549	0.0108
ROI3	1.759	0.303	5.789	<0.0001	1.047	0.303	3.448	0.0006	−0.141	0.304	−0.466	0.6410	0.003	0.304	0.011	0.9911
ROI4	1.893	0.305	6.201	<0.0001	1.180	0.304	3.871	0.0001	−0.008	0.305	−0.028	0.9779	0.136	0.305	0.447	0.6547
VOS																
	ROI1				ROI2				ROI3				ROI4			
VSO	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*
ROI1	0.134	0.304	0.442	0.6588	−0.010	0.303	−0.033	0.9733	−0.866	0.303	−2.852	0.0043	−1.926	0.305	−6.314	<0.0001
ROI2	0.972	0.304	3.194	0.0014	0.827	0.303	2.725	0.0064	−0.028	0.304	−0.094	0.9255	−1.088	0.305	−3.565	0.0004
ROI3	1.634	0.304	5.360	<0.0001	1.490	0.304	4.897	<0.0001	0.634	0.304	2.081	0.0374	−0.426	0.306	−1.394	0.1634
ROI4	1.926	0.304	6.316	<0.0001	1.781	0.304	5.855	<0.0001	0.925	0.304	3.038	0.0024	−0.134	0.306	−0.441	0.6594

Notes: ROI = region of interest; ROI1 = first constituent of the sentence; ROI2 = second constituent of the sentence; ROI3 = third constituent of the sentence; ROI4 = post-offset region. Significance level $p < 0.003$ with Bonferroni's correction for multiple comparison.

Table 12. Comparison of proportion of gaze fixations between verb-final (SOV and OSV) and verb-initial (VSO and VOS) conditions across ROIs, in correctly answered trials in PWA group.

	OSV															
	ROI1				ROI2				ROI3				ROI4			
SOV	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*
ROI1	0.200	0.357	0.559	0.5760	−0.284	0.360	−0.791	0.4292	−0.949	0.360	−2.632	0.0085	−1.192	0.359	−3.321	0.0009
ROI2	1.087	0.358	3.033	0.0024	0.602	0.361	1.668	0.0952	−0.062	0.361	−0.172	0.8636	−0.304	0.359	−0.846	0.3974
ROI3	1.312	0.357	3.670	0.0002	0.827	0.360	2.297	0.0216	0.162	0.360	0.452	0.6516	−0.079	0.358	−0.222	0.8247
ROI4	1.271	0.359	3.536	0.0004	0.786	0.362	2.171	0.0299	0.121	0.362	0.335	0.7374	−0.120	0.360	−0.335	0.7377
	VOS															
	ROI1				ROI2				ROI3				ROI4			
VSO	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*
ROI1	−0.495	0.359	−1.380	0.1676	−0.428	0.362	−1.184	0.2366	−0.911	0.359	−2.534	0.0113	−1.211	0.360	−3.358	0.0008
ROI2	0.342	0.360	0.950	0.3422	0.409	0.363	1.125	0.2604	−0.074	0.361	−0.205	0.8375	−0.374	0.362	−1.033	0.3017
ROI3	1.037	0.360	2.879	0.0040	1.103	0.363	3.038	0.0024	0.620	0.360	1.720	0.0855	0.320	0.362	0.886	0.3757
ROI4	0.935	0.362	2.581	0.0099	1.002	0.365	2.742	0.0061	0.519	0.363	1.429	0.1530	0.218	0.364	0.601	0.5477

Notes: ROI = region of interest; ROI1 = first constituent of the sentence; ROI2 = second constituent of the sentence; ROI3 = third constituent of the sentence; ROI4 = post-offset region. Significance level $p < 0.003$ with Bonferroni's correction for multiple comparison.

Table 13. Comparison of proportion of gaze fixations between verb-final (SOV and OSV) and verb-initial (VSO and VOS) conditions across ROIs, in incorrectly answered trials in PWA group.

	OSV															
	ROI1				ROI2				ROI3				ROI4			
SOV	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*
ROI1	−0.412	0.460	−0.896	0.3702	0.004	0.458	0.011	0.9913	0.251	0.459	0.546	0.5848	0.234	0.461	0.507	0.6124
ROI2	−0.530	0.460	−1.153	0.2491	−0.113	0.457	−0.247	0.8051	0.133	0.459	0.290	0.7720	0.116	0.461	0.251	0.8016
ROI3	−0.248	0.453	−0.548	0.5836	0.168	0.451	0.375	0.7080	0.415	0.452	0.917	0.3590	0.397	0.454	0.875	0.3816
ROI4	−0.863	0.456	−1.891	0.0587	−0.446	0.454	−0.982	0.3263	−0.199	0.455	−0.438	0.6610	−0.216	0.458	−0.474	0.6358
	VOS															
	ROI1				ROI2				ROI3				ROI4			
VSO	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*	*β*	SE	*z*-Ratio	*p*
ROI1	−0.051	0.446	−0.115	0.9087	0.552	0.443	1.244	0.2133	1.199	0.443	2.704	0.0069	1.285	0.445	2.883	0.0039
ROI2	−0.302	0.444	−0.682	0.4954	0.300	0.441	0.681	0.4958	0.948	0.441	2.148	0.0317	1.033	0.443	2.331	0.0197
ROI3	−0.288	0.447	−0.645	0.5187	0.314	0.444	0.707	0.4794	0.962	0.444	2.163	0.0305	1.047	0.446	2.345	0.0190
ROI4	−0.930	0.451	−2.058	0.0396	−0.326	0.449	−0.727	0.4671	0.320	0.448	0.715	0.4747	0.406	0.451	0.902	0.3672

Notes: ROI = region of interest; ROI1 = first constituent of the sentence; ROI2 = second constituent of the sentence; ROI3 = third constituent of the sentence; ROI4 = post-offset region. Significance level $p < 0.003$ with Bonferroni's correction for multiple comparison.

Table 14. Comparison of the linear predictor of gaze-fixation data with zero in each sentence condition and ROI in both NBD and PWA groups.

		NBD correct			PWA correct			PWA incorrect		
Condition	ROI	LSM (95% CI)	*t* (df)	*p*	LSM (95% CI)	*t* (df)	*p*	LSM (95% CI)	*t* (df)	*p*
SOV	ROI1	0.10 (−0.33–0.54)	0.473 (142)	0.6368	0.27 (−0.19–0.74)	1.140 (115)	0.2565	−0.54 (−1.29–0.19)	1.448 (36)	0.1562
	ROI2	0.70 (0.25–1.14)	3.118 (142)	0.0022	1.16 (0.68–1.63)	4.272 (115)	<0.0001	−0.66 (−1.40–0.07)	1.761 (36)	0.0866
	ROI3	1.48 (1.03–1.92)	6.546 (142)	<0.0001	1.38 (0.91–1.85)	5.797 (115)	<0.0001	−0.38 (−1.10–0.34)	1.038 (36)	0.3060
	ROI4	1.61 (1.16–2.06)	7.083 (142)	<0.0001	1.34 (0.86–1.82)	5.686 (115)	<0.0001	−0.99 (−1.73–−0.26)	2.673 (36)	0.0112
OSV	ROI1	−0.27 (−0.72–0.16)	1.241 (143)	0.2164	0.07 (−0.48–0.62)	0.260 (70)	0.7954	−0.13 (−0.68–0.41)	0.483 (81)	0.6300
	ROI2	0.43 (−0.00–0.87)	1.926 (143)	0.0560	0.55 (−0.00–1.11)	1.951 (70)	0.0550	−0.55 (−1.09–−0.01)	1.998 (81)	0.0490
	ROI3	1.62 (1.17–2.06)	7.208 (143)	<0.0001	1.22 (0.66–1.78)	4.271 (70)	<0.0001	−0.79 (−1.34–−0.25)	2.865 (81)	0.0053
	ROI4	1.47 (1.03–1.91)	6.543 (143)	<0.0001	1.46 (0.90–2.02)	5.185 (70)	<0.0001	−0.78 (−1.33–−0.22)	2.767 (81)	0.0070
VSO	ROI1	−0.09 (−0.52–0.34)	0.415 (147)	0.6781	−0.28 (−0.77–0.20)	1.127 (104)	0.2622	−0.08 (−0.77–0.60)	0.231 (42)	0.8179
	ROI2	0.74 (0.30–1.18)	3.357 (147)	0.0010	0.55 (0.06–1.05)	2.198 (104)	0.0301	−0.33 (−1.01–0.35)	0.953 (42)	0.3457
	ROI3	1.40 (0.96–1.84)	6.316 (147)	<0.0001	1.25 (0.75–1.74)	5.036 (104)	<0.0001	−0.31 (−1.01–0.37)	0.904 (42)	0.3708
	ROI4	1.69 (1.25–2.13)	7.612 (147)	<0.0001	1.14 (0.64–1.64)	4.644 (104)	<0.0001	−0.96 (−1.66–−0.25)	2.675 (42)	0.0106
VOS	ROI1	−0.22 (−0.67–0.22)	0.991 (136)	0.3232	0.21 (−0.32–0.75)	0.773 (77)	0.4418	−0.03 (−0.60–0.54)	0.104 (70)	0.9169
	ROI2	−0.08 (−0.52–0.36)	0.362 (136)	0.7177	0.14 (−0.40–0.69)	0.523 (77)	0.6025	−0.63 (−1.19–−0.07)	2.209 (70)	0.0304
	ROI3	0.77 (0.325–1.22)	3.394 (136)	0.0009	0.62 (0.08–1.17)	2.278 (77)	0.0255	−1.28 (−1.84–−0.71)	4.575 (70)	<0.0001
	ROI4	1.83 (1.38–2.28)	7.667 (136)	<0.0001	0.92 (0.38–1.47)	4.104 (77)	0.0001	−1.36 (−1.93–−0.79)	4.762 (70)	<0.0001

Notes: ROI = region of interest; ROI1 = first constituent of the sentence; ROI2 = second constituent of the sentence; ROI3 = third constituent of the sentence; ROI4 = post-offset region. Significance level $p < 0.05$.

commitment to look towards the target picture at the same time window across all sentence conditions. In SOV and VSO sentence conditions participants fixated the target picture from ROI2 onwards, corresponding to object and subject presentation, respectively. In sentences presented in OSV and VOS conditions, proportions of fixations towards the target picture were significant at ROI3, verb and subject position, respectively. In OSV sentence condition, fixations towards the target picture were marginally significant at subject position in both NBD and PWA groups.

In the incorrectly answered trials, PWA participants did not significantly fixated into the foil picture until the ROI4 in SOV or VSO sentence conditions. Thus, although in average PWA looked more towards the foil picture from early on the sentences, the proportion of fixations did not achieved significance until the post-offset silence. In contrast, in sentences presented in OSV and VOS sentence conditions, PWA significantly fixated into the foil picture at ROI2, corresponding to subject and object position, respectively.

Third, we compared the fixation pattern of the NBD and PWA groups in the correctly responded stimuli. Pairwise comparisons of each ROI across the sentence conditions were conducted between groups (see Table 15). The results revealed that there were no differences between the groups for the fixation pattern for the visual stimuli in each ROI across the different sentence conditions, with the exception of the post-offset region in the VOS condition. In this case, there were significantly fewer fixations to the correct picture for the PWA group than for the NBD group. Apart from that, in the correctly answered trials, the gaze data of NBD and PWA groups were indistinguishable based on the progressive increase in fixations towards the correct stimulus over time.

Fourth, we compared the fixation patterns of the PWA group between correctly and incorrectly answered stimuli. This yielded significant differences, as illustrated in Figure 4. Correct and incorrect answers were statistically distinguishable from the ROI2 onward in the SOV (i.e. object position), OSV (i.e. subject position), VSO (i.e. subject position) and VOS (i.e. object position) sentence conditions, as detailed in Table 16.

In this section we have analysed behavioural and gaze data from PWA and NBD groups while performing a picture-matching task. Accuracy data have pointed out that the order of the arguments within a sentence has a significant effect on the comprehension deficits of the PWA group. Sentences containing linear A-T order of arguments were understood significantly better than sentences with the inversed order of constituents. The RT data have shown no significant differences between groups, presumably due to high variability in the PWA group. In line with this, within-group comparison has uncovered no differences across sentence conditions in the PWA group. Conversely, the NBD group has shorter RTs in base word order (i.e. SOV) in relation to OSV and VOS, contrary to VSO word order. These data converge with the fixation pattern analysed. The analysis of the visual resolution point suggests that PWA take a commitment towards fixating to the target picture from the second argument in verb-final (i.e. SOV and OSV) and at subject position in verb-initial (i.e. VSO and VOS) sentences. The fixation patterns always diverged at ROI2 between correctly and incorrectly answered trials. Fixation patterns shown in correctly answered trials are indistinguishable, in both timing and proportion, between the PWA and NBD group, except in the proportion of fixations on the post-offset region of the VOS.

Table 15. Between-group comparison of the gaze fixations patterns in the correct answers as a function of ROI and sentence conditions.

		LSMeans (95% CI)	*β*	SE	*z*-Ratio	*p*		LSMeans (95% CI)	*β*	SE	*z*-Ratio	*p*
			SOV						OSV			
ROI1	NBD	0.10 (−0.33–0.54)	−0.166	0.321	−0.52	0.6033	NBD	−0.27 (−0.72–0.16)	−0.353	0.353	−0.998	0.3182
	PWA	0.27 (−0.19–0.74)					PWA	0.07 (−0.48–0.62)				
ROI2	NBD	0.70 (0.25–1.14)	−0.459	0.322	−1.426	0.1538	NBD	0.43 (−0.00–0.87)	−0.125	0.356	−0.353	0.7240
	PWA	1.16 (0.68–1.63)					PWA	0.55 (−0.00–1.11)				
ROI3	NBD	1.48 (1.03–1.92)	0.093	0.321	0.291	0.7708	NBD	1.62 (1.17–2.06)	0.398	0.357	1.116	0.2646
	PWA	1.38 (0.91–1.85)					PWA	1.22 (0.66–1.78)				
ROI4	NBD	1.61 (1.16–2.06)	0.268	0.325	0.826	0.4088	NBD	1.47 (1.03–1.91)	0.010	0.355	0.03	0.9758
	PWA	1.34 (0.86–1.82)					PWA	1.46 (0.90–2.02)				
			VSO						VOS			
ROI1	NBD	−0.09 (−0.52–0.34)	0.189	0.327	0.58	0.5619	NBD	−0.22 (−0.67–0.22)	−0.439	0.350	−1.256	0.2092
	PWA	−0.28 (−0.77–0.20)					PWA	0.21 (−0.32–0.75)				
ROI2	NBD	0.74 (0.30–1.18)	0.189	0.328	0.577	0.5641	NBD	−0.08 (−0.52–0.36)	−0.228	0.352	−0.648	0.5169
	PWA	0.55 (0.06–1.05)					PWA	0.14 (−0.40–0.69)				
ROI3	NBD	1.40 (0.96–1.84)	0.157	0.329	0.478	0.6327	NBD	0.77 (0.32–1.22)	0.144	0.350	0.411	0.6811
	PWA	1.25 (0.75–1.74)					PWA	0.62 (0.08–1.17)				
ROI4	NBD	1.69 (1.25–2.13)	0.550	0.331	1.66	0.0969	NBD	1.83 (1.38–2.28)	0.904	0.353	2.562	0.0104
	PWA	1.14 (0.64–1.64)					PWA	0.92 (0.38–1.47)				

Notes: ROI = region of interest; ROI1 = first constituent of the sentence; ROI2 = second constituent of the sentence; ROI3 = third constituent of the sentence; ROI4 = post-offset region. Significance level $p < 0.05$.

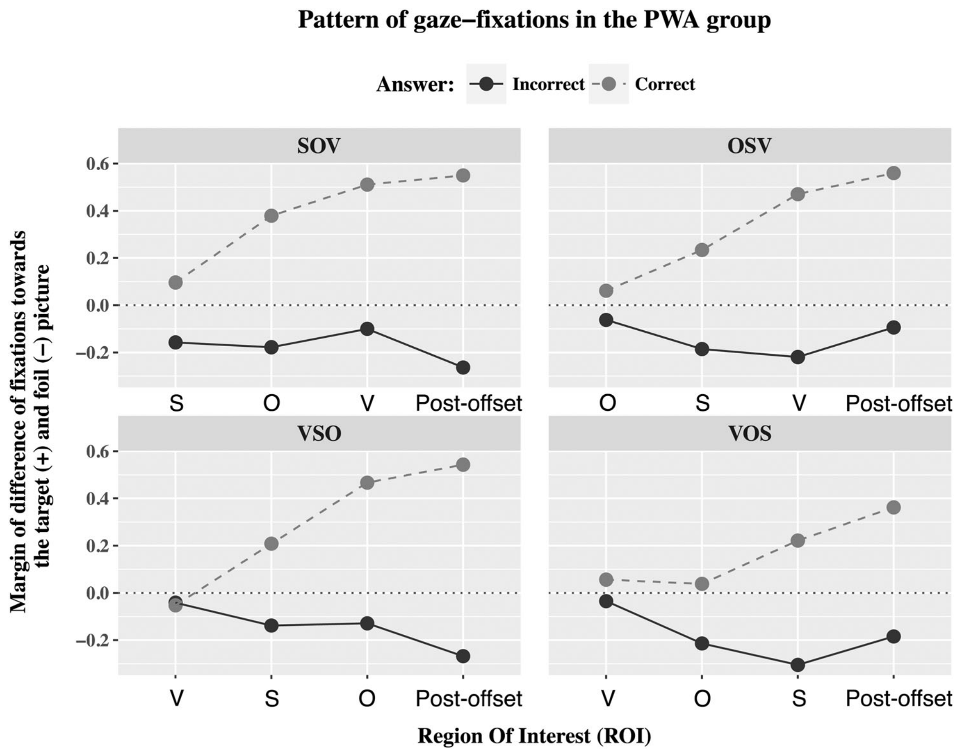

Figure 4. Gaze-fixation pattern across the visual stimuli during the auditory presentation of the sentence. Comparison between the correct and incorrect answers in the PWA group.

Table 16. Comparison of gaze-fixation patterns as a function of ROI and response accuracy in PWA group.

		LSMeans (95% CI)	*β*	SE	*z*-Ratio	*p*		LSMeans (95% CI)	*β*	SE	*z*-Ratio	*p*
			SOV						OSV			
ROI1	I	−0.54 (−1.29–0.19)	−0.821	0.437	−1.879	0.0603	I	−0.13 (−0.68–0.41)	−0.209	0.386	−0.541	0.5882
	C	0.27 (−0.19–0.74)					C	0.07 (−0.48–0.62)				
ROI2	I	−0.66 (−1.40–0.07)	−1.827	0.438	−4.172	<0.0001	I	−0.55 (−1.09−−0.01)	−1.111	0.386	−2.878	0.0040
	C	1.16 (0.68–1.63)					C	0.55 (−0.00–1.11)				
ROI3	I	−0.38 (−1.10–0.34)	−1.770	0.430	−4.117	<0.0001	I	−0.79 (−1.34−−0.25)	−2.022	0.388	−5.208	<0.0001
	C	1.38 (0.91–1.85)					C	1.22 (0.66–1.78)				
ROI4	I	−0.99 (−1.73−−0.26)	−2.344	0.435	−5.387	<0.0001	I	−0.78 (−1.33−−0.22)	−2.248	0.389	−5.773	<0.0001
	C	1.34 (0.86–1.82)					C	1.46 (0.90–2.02)				
			VSO						VOS			
ROI1	I	−0.08 (−0.77–0.60)	0.200	0.421	0.476	0.6338	I	−0.03 (−0.60–0.54)	−0.243	0.389	−0.625	0.5317
	C	−0.28 (−0.77–0.20)					C	0.21 (−0.32–0.75)				
ROI2	I	−0.33 (−1.01–0.35)	−0.888	0.420	−2.114	0.0345	I	−0.63 (−1.19−−0.07)	−0.780	0.388	−2.007	0.0448
	C	0.55 (0.06–1.05)					C	0.14 (−0.40–0.69)				
ROI3	I	−0.31 (−1.01–0.37)	−1.569	0.423	−3.703	0.0002	I	−1.28 (−1.84−−0.71)	−1.910	0.386	−4.945	<0.0001
	C	1.25 (0.75–1.74)					C	0.62 (0.08–1.17)				
ROI4	I	−0.96 (−1.66−−0.25)	−2.109	0.430	−4.904	<0.0001	I	−1.36 (−1.93−−0.79)	−2.296	0.389	−5.892	<0.0001
	C	1.14 (0.647–1.64)					C	0.92 (0.38–1.47)				

Notes: ROI = region of interest; ROI1 = first constituent of the sentence; ROI2 = second constituent of the sentence; ROI3 = third constituent of the sentence; ROI4 = post-offset region; I = incorrect answer; C = correct answer. Significance level $p < 0.05$.

In the current experiment, two out of eight participants (A3–A8) performed above-chance level on the experimental task, although they had shown chance-level scores in the pre-test. Working memory limitations may explain these discrepancies depending on the length of the linguistic stimuli, as suggested by Miyake, Carpenter, and Just (1994). These two participants scored in a rather low percentile of the digit-span task for their age, suggesting poor working memory functioning. This may prevent them from fully comprehending longer sentences such as the ones presented in the CNL language screening battery (Chialant, 2000; adapted to Basque by Erdocia, Santesteban, & Laka, 2003) while comprehension of the shorter sentences on the experimental task was relatively well-preserved. The other PWA showed variable performance across conditions, but in each case sentences with derived order of the arguments were significantly less well understood than sentences in which the arguments were in base order.

5. Discussion

In the current study we aimed to provide further insight into: (a) the effect of the order of the arguments on sentence comprehension deficits of PWA in a free word order language; (b) the validity of the TDH (Drai & Grodzinsky, 2006a, 2006b; Grodzinsky, 1986, 1995, 2000) and DOP-H (Bastiaanse & Van Zonneveld, 2006) to explain online and offline sentence comprehension in aphasia. Based on representational and processing perspectives, the TDH and DOP-H have proposed diverging explanations about the underlying deficits that PWA face in sentence processing. This study confronts these hypotheses with results from processing a free word order and morphologically rich language and draws attention to certain cross-linguistic universals in sentence comprehension deficits in PWA.

5.1. Sentence comprehension accuracy and RTs

The findings of this study reveal that the PWA group had a poorer sentence comprehension than the control group regardless of the word order in which the sentence was presented. Since we demonstrated that the PWA in this study had preserved lexical comprehension, difficulties in the comprehension of sentences presented with base word order (i.e. SOV) indicate difficulties in syntactic processing. The comprehension of sentences presented in SOV and VSO order was not intact, but still above chance. Thus, these results converge with the two hypotheses tested in this paper.

Within-group comparisons confirmed differences between conditions. When we compared the results of PWA across conditions, there was no difference between the SOV and VSO order. They turned out to perform worse on OSV and VOS than on SOV and VSO conditions, although OSV and VOS sentences are more frequent than VSO in Basque (Aldezabal et al., 2003). Hence, the error pattern found cannot be explained as a function of frequency of use of the structure in Basque. This finding converges with that of Bornkessel et al. (2002), who observed that neurophysiologically distinct responses were observed on the basis of the linguistic properties of the stimuli, but not as a function of the frequency of these structures in a given language. In addition, the NBD group performed equally well on all structures. Thus, differences across conditions support the predictions of the DOP-H and do not support the predictions of the TDH (see Drai & Grodzinsky, 2006a, 2006b).

In contrast to previous studies reporting longer RTs for PWA than for healthy listeners (Caplan & Waters, 2003; Hanne et al., 2011), PWA participating in the current study did not show significantly longer latencies to provide an answer than the NBDs. RT of correctly and incorrectly answered trials did not discern in the PWA group. These results do not seem to support the cognitive slowdown as the deficit source of comprehension impairment in PWA. However, exploratory analysis of the data suggests a trend for longer RTs in the PWA group across all sentence types. It is possible that the rather small sample size and large variability in the PWA group may prevent reaching statistical significance. PWA presented a trend for larger RTs than NBD independently of base or derived order of the sentence, a trend that is compatible with the processing account rationale (Burkhardt et al., 2003, 2008; Caplan, 2006; Caplan et al., 2007; Dickey et al., 2007; Haarmann & Kolk, 1991).

Contrary to what the DOP-H suggests, the PWA group did not respond quicker to sentences presented in base word order (i.e. SOV) than to the ones with derived order. Meanwhile, the NBD group answered faster to SOV word order sentences than to those in OSV and VOS order. These results converge with previous studies demonstrating that healthy speakers benefit from sentences with canonical argument order since they use an agent-first strategy to process them (Erdocia et al., 2009). Notice that the requirement for reanalysis in OSV sentences does not imply longer RTs than for VOS sentences, where listeners may assign the thematic roles unambiguously already to the first DP, thanks to the information about grammatical functions on the verb.

Altogether, the behavioural data suggest that PWA have difficulties in assigning thematic roles to DPs in OSV word order sentences, which requires syntactic reanalysis. In addition, they present deficits in making use of the information provided by verbal morphology and case marking to disentangle the thematic role assignment in the case of VOS word order sentences. This may be either because PWA do not fully access the argument structure of the lexical verb and/or inflection information of the verb. An alternative interpretation could be that the application of a linear A-T strategy overrides the information provided by case and agreement morphology. Discussion on gaze data will shed light into this topic in the next section.

5.2. Gaze-fixation data

Online language processing data are informative to check the validity of the different theoretical approaches. Using this methodology, we can identify a guessing pattern and diminished grammatical parsing routines that were proposed as potential causes of these deficits by the TDH and DOP-H, respectively.

Within-group analysis of the fixation patterns across the different sentence types reveals two main things: One, in both verb-final (i.e. SOV and SOV) and verb-initial (i.e. VSO and VOS) conditions, the auditory presentation of the agentive subject prior to the object provided the listeners with an advantage to disentangle the thematic role assignment, whereas this was not the case when the object was presented before the agentive subject. Two, in the correctly comprehended trials, both NBD and PWA visually resolved the sentence in the vicinity of the subject across all sentence conditions. Participants resolved the sentences after and during the presentation of the subject in verb-final and verb-initial conditions, respectively.

Results suggest that in the correctly answered trials both NBD and PWA strongly relied on the case mark signalling the Agent (i.e. ergative) to interpret the sentence, whereas the absolutive case morphology that marked the Theme did not considerably guide the parsing routine. Listeners waited until the presentation of the ergative case marking affixed to the subject to disentangle the thematic role parsing across all sentence conditions. In addition, the data have shown that the position of the verb in the sentence also has an impact on case morphology processing, as well as on subsequent thematic role parsing. Both NBD and PWA resolved the sentence earlier in the VSO than in the SOV sentence condition. In VSO, in which the verb inflection provides information about the transitivity and number of arguments of the verb, both NBD and PWA parsed the first DP simultaneously to its presentation, whereas in absence of verbal information (i.e. SOV), the processing of case marking at the first DP was delayed to the subsequent ROI. The fast resolution of VSO sentences, even prior to the presentation of the second DP is compatible with the anticipatory thematic role assignment described in other case marking languages (Kamide, Altmann, et al., 2003; Kamide, Scheepers, et al., 2003; Knoeferle et al., 2005). At the same time, the absence of the anticipatory thematic role assignment in VOS sentence conditions in both NBD and PWA groups confirms the higher cognitive demand for processing T-A word order, as suggested by the DOP-H (Bastiaanse & Van Zonneveld, 2006), even when the absolutive case marking unambiguously marks the Theme. These results shed light onto the trend set by the RT data; that is, they suggest that incorrect answers in the PWA group are motivated by deficits in the thematic role assignment to specific arguments in the sentence, and not by a complete failure to access argument structure information. Overall, data suggest that PWA do access the argument structure information at the verb position to some extent, but have difficulty processing the case morphology that guides the assignment of the thematic roles to specific DPs (Grodzinsky, 1986; Shapiro & Levine, 1990). Severe impairment in the processing of case morphology was also reported by Burchert et al. (2003) in a group of German agrammatic speakers. Still, in line with that study, individual analyses of PWA participants in the current study suggest that not all PWA with comprehension impairments have these deficits to the same degree.

The fixation proportion towards the target picture while presented with the subject at SOV and OSV sentences conditions were indistinguishable in both NBD and PWA. Recall that OSV structures were temporarily ambiguous. Previous studies have shown that unimpaired Basque speakers interpret the initial DP as the subject of an unaccusative verb, and reanalyse the initial parsing when they encounter the second DP marked with the ergative case (Erdocia et al., 2009). However, abovementioned results do not suggest an attempt of such a reanalysis in either group. The null-effect may be related to the agglutinative character of the case marking morphology. Note that the case morphology is affixed to the arguments and it appears at the end of each time window (i.e. ROI). Thus, the fixation shift motivated by the presentation of the case morphology may be visible in the subsequent ROI, because the 200 ms correction applied in the gaze data to align it with the linguistic stimuli (see Matin et al., 1993) may not be accurate enough. This idea has been supported by the visual resolution analysis, where we have identified in which time window participants made a commitment to look towards the target or foil picture. The data have showed that NBD and PWA groups marginally resolved the sentence at subject position in OSV sentences, prior to the disambiguation point.

In the incorrectly answered trials, PWA progressively fixated onto the foil picture along the presentation of the sentences. Opposite to the correctly answered trials, in SOV and VSO sentence conditions PWA randomly looked at target and foil pictures along the presentation of the sentence until the post-offset silence, where they made a commitment to fixate to the foil picture. In VOS sentence conditions, PWA showed an early commitment to fixate towards the foil picture in the object position, whereas in OSV it was delayed until the subject position. The fact that PWA resolved faster VOS than OSV sentences suggests that also in the incorrectly answered trials, PWA remain sensitive to verb inflectional information, although subsequently fail to parse thematic roles into the DPs. Sentence resolution at the subject position in OSV sentences is not compatible with the fact that PWA may parse the sentence-initial DP as the subject of an unaccusative verb (see Erdocia et al., 2009), since they committed to an interpretation even prior to the disambiguation point (i.e. offset of the subject). We believe that this pattern, as well as the one described in the correctly answered OSV sentences, is due to methodological constrains that will be discussed at the end of this section.

Between-group analysis of the fixation patterns of PWA and NBD across different sentence types reveals two main things: One, there were no different gaze patterns for correct trials for the two groups. Two, the gaze-fixation patterns of PWA in the correct answers were different from the correct trials for all word orders. In the correctly answered trials, the fixation pattern along the presentation of each argument of the sentence was indistinguishable between the groups. There was one exception, which corresponds to the post-offset region in the VOS sentence type, in which participants from the PWA group fixated less often to the correct picture, although they answered correctly. This may be related to the longer RTs of the PWA's comprehension in this word order. Recall that visual resolution analysis in the VOS sentence condition suggests that both PWA and NBD settled to a sentence interpretation while presented with the ergative case marker of the subject. However, between-group comparison points out that PWA took longer than NBD to integrate the case information into the syntactic structure. The data suggest that when both the argument order and the verb position are derived, the cost of integrating these information cues may slowdown sentence processing of PWA. This is in line with the ERP findings of Kielar et al. (2012), who showed that processing verb arguments in PWA is not always complete. In addition, it converges with the "Integration Problem Theory" of Duman et al. (2011), which explains the nature of the deficits by integrating both word order and base case marking in agrammatic Turkish speakers.

The analysis of the visual resolution of the sentences shows not only that PWA and NBD participants process sentences similarly when they point to the correct picture, but also that they do so fairly time-aligned for each argument of the sentence, contrary to what was found by Hanne et al. (2011) (see also Meyer et al., 2012). Our findings also contradict the slowdown framework within the processing account. If we assume that the slowing down of basic cognitive functions is the cause of language processing deficits in PWA, a delayed application of the same routines of the NBD group is expected. However, PWA in the current study showed the same rapid, automatic processing of sentences as the NBDs. Interestingly, these results converge with another ET study on the comprehension of *wh*-questions conducted by Dickey et al. (2007). They concluded that contrary to what representational and processing accounts suggest PWA processed *wh*-questions like healthy listeners in the correctly answered trials. In line with their claim, we think that it is possible that previous studies implying consciously controlled responses may have slightly biased online measures because of the involvement of a secondary cognitive task, such as a button press. Still, Hanne et al. (2011), who used ET, have shown real-time processing delays as measured by gaze-fixation patterns. We believe that the procedures used in the current study and in the study of Dickey et al. (2007) may not detect subtle processing delays, because the temporal windows in which the data are analysed are too wide for this purpose. Therefore, we can only conclude that PWA do not present an aberrant processing delay compared to the NBD group.

So far we have shown that correctly interpreted sentences were processed similarly by both PWA and NBD groups. In addition to this, a comparison of the fixation patterns of PWA across correct and incorrect trials supported a non-guessing pattern in PWA (see Burchert et al., 2013 for a review). In line with previous literature (Dickey et al., 2007; Hanne et al., 2011), the fixation advantage towards the target picture was different for the correctly and incorrectly answered trials. For the correctly answered trials, the advantage of fixations on the correct pictures showed a progressive increase, while for incorrectly answered trials the same pattern of looks towards the picture with the reverse interpretations was observed. The time resolution of these divergences was the same across sentence types (i.e. second ROI).

These results point out that PWA show an early tendency to look towards the target or the foil picture, in correctly and incorrectly answered trials, respectively. In the SOV and VSO condition, correctly and incorrectly answered trials diverge from the second argument onward, which is the same time window in which PWA commit to fixate onto the target picture in correctly answered sentences in these conditions. However, the time window in which the gaze-fixation pattern of correct and incorrect answers differs is not always shared with the sentence resolution point, as is the case in OSV and VOS sentences. When we analyse VSO and VOS together, data indicate that PWA tend to use the agent-first strategy that leads to the correct interpretation in the VSO condition and incorrect interpretation in the VOS condition. Note that in the latter the difference of fixations between correctly and incorrectly answered trials at the object position is due to the increase of fixations on the incorrect picture in the incorrect answers. However, in VOS sentences PWA showed a slow increase of fixations onto the correct picture, and visual resolution of the correctly answered sentences took place later, at subject position. This advocates that Agent-first bias is not absent in agrammatic aphasia, as suggested by Meyer et al. (2012) in the on-line study of passive sentence processing, but it is detected in the first DP in verb-initial sentences. This pattern reinforces the claim that PWA are sensitive to the verb information, which favours faster assignment of thematic roles based on case morphology in relation to verb-final sentence conditions.

This fixation pattern in OSV condition provides additional evidence for NBD and PWA not being sensitive to the temporal ambiguity of these constructions. The underlying processing of the sentence marginally distinguishes correctly and incorrectly answered trials even before the disambiguation point. We believe that the absence of any sign of reanalysis in NBD and PWA may be related to the methodological constraints of the experiment. In our sentence–picture-matching task, the visual material depicting two reverse scenes was present before and during the auditory presentation of the sentence. We included filler sentences with unaccusative verbs to keep constant the need for reanalysis during the task. However, the visual stimuli may have provided the listeners with enough information about the transitivity of the verb as consolidated by learning effect along the experiment.[4] That is, listeners may develop an inference rationale to know the transitivity of the verb as soon as the image was presented, which overrides the garden path effect on OSV structures. This explanation is also compatible with the effect of trial number on the RT data. NBD become faster answering SOV and OSV sentences along the experiment. Progressively, the inference strategy may override the temporal ambiguity and subsequent reanalysis requirement in OSV sentences. Marginal significances at subject position suggest that the reanalysis process may be cancelled along the progression of the experiment.

This rationale is related to a broader task-specific influence on sentence processing. The gaze-fixation patterns in correctly and incorrectly answered trials have diverged from early on in the presentation of the stimuli across all sentence conditions. This early deviation coincides with previous findings using sentence–picture-matching tasks in the VWP (Hanne et al., 2011; cf. Meyer et al., 2012). In contrast, late emerging differences as a function of response accuracy have been shown in other studies using self-paced listening grammaticality judgment (Caplan & Waters, 2003; Caplan et al., 2007) and the classical VWP[5] (Dickey et al., 2007).

Such differences are not unequivocally related to the linguistic stimuli, but refer to the online interaction between the syntactic processing and the specific requirements of the task (see Caplan, 2006; Caplan, Michaud, & Hufford, 2013). In a sentence–picture-matching task, such as the one used in the current experiment, the visual stimulus depicts the thematic roles that will subsequently be presented in the target sentence, contrary to tasks involving the visual representation of single entities (Caplan & Waters, 2003; Caplan et al., 2007; Dickey et al., 2007). Therefore, the setting of sentence–picture-matching tasks provides the listener with some expectations, which may not necessarily benefit PWA. Being visually presented with the target and foil scenes before and during the presentation of the sentence may also impose higher demands inhibiting the representation of the distractor (i.e. foil picture) and, as executive/control requirements vary, it may interfere with comprehension accuracy. This interpretation is consistent with previous findings suggesting that specific linguistic operations are not equally impaired across tasks, because task-related operations also influence or trigger comprehension failure (Caplan, 2006; Caplan et al., 2013).

6. Conclusions

The effect of word order on sentence comprehension in PWA has been a focus of research for decades. This study contributes to the debate by introducing data from a richly inflected ergative language with free word order, and helps to disentangle the relationship between language properties and the cognitive demand that distinct word orders may impose on PWA.

The current study aimed to investigate the effect of word order on sentence comprehension deficits in PWA speakers of Basque. The results suggest that although the PWA demonstrated preserved lexical comprehension, at group level sentence comprehension is poorer than that of NBDs, both for sentences with base word order and for sentences with derived word orders. This contradicts the predictions made by the TDH (as formulated in Drai & Grodzinsky, 2006a, 2006b), but not the original version of this hypothesis (Grodzinsky, 1986, 1995, 2000). That is, PWA were more impaired in their comprehension of sentences in which there was no linear A-T argument order, regardless of the position of the verb.

For the correct answers, both PWA and NBD visually resolute the sentence at the same time window across all word orders. In addition, real-time fixation patterns of PWA during the presentation of the auditory stimuli were indistinguishable from the NBD group, with a single exception (i.e. post-offset of VOS). However, the pattern diverged for the incorrectly answered trials. This suggests that the correct answers of PWA are due to control-wise language processing and not caused by guessing as suggested by the TDH. No general delay in sentence processing was found in the PWA group, suggesting that the PWA taking part in this study present a control-wise rapid and automatic processing of linguistic stimuli for sentences they answered correctly. This converges with the findings of Dickey et al. (2007) and suggests that there is inconsistent grammatical parsing, compatible with the DOP-H and other processing accounts. Still, the results need to be interpreted with caution, since they do not necessarily imply that both groups process the stimuli with the same speed; the delay may not have been large enough to be detected with the current methodology and data analysis used in this study.

Altogether, the study suggests that word order has a significant effect on the sentence comprehension abilities of PWA speakers of free word order languages. Thus, the order in which arguments are perceived influences sentence processing, regardless of the morphological information carried by the verb and the DPs. Hence, sentences in which the Theme precedes the Agent are harder to process and comprehend than A-T sentences, independently of the corpus frequency of the sentences in question. PWA present with serious problems in processing case morphology, even when they are sensitive to the argument structure of the verb; their comprehension performance decreases depending on the demand imposed by the word order, as suggested by the DOP-H.

Notes

1. Following Kayne (1994) and Fukui and Takano (1998), we assume that there is no rightward movement of the arguments within the sentence. Thus, the only possible derivations for (12–14) are the ones shown in this section.
2. Currently Basque speaking monolinguals are rare, since both Spanish and French are required by law, depending on geopolitical territories.
3. Only gaze-fixation analysis of the correctly answered trials are reported in the NBD group, due to the marginal number of incorrect answers.
4. Most of the visual stimuli in the filler trials depicted one single character, whereas target trials always depicted two characters.
5. In the classical visual world paradigm, an array of single objects presented in the linguistic stimuli is segregated along visual display, in addition to several distractors (e.g. Dickey et al., 2007; Kamide, Altmann, et al., 2003; Kamide, Scheepers, et al., 2003).

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